Atti Accademia Nazionale dei Lincei

Classe Scienze Fisiche Matematiche Naturali

Rendiconti

Marcello Beneventano, Silio D'Angelo, Francesco DE Notaristefani, Piero Monacelli, Luciano Paoluzi, Fabio Sebastiani, Marco Severi

«Impulse approximation» calculation of the polarization of the recoil proton in the reaction $\gamma + n \rightarrow p + \pi^-$ in deuterium

Atti della Accademia Nazionale dei Lincei. Classe di Scienze Fisiche, Matematiche e Naturali. Rendiconti, Serie 8, Vol. **47** (1969), n.6, p. 509–513.

Accademia Nazionale dei Lincei

<http://www.bdim.eu/item?id=RLINA_1969_8_47_6_509_0>

Atti della Accademia Nazionale dei Lincei. Classe di Scienze Fisiche, Matematiche e Naturali. Rendiconti, Accademia Nazionale dei Lincei, 1969.

SEZIONE II

(Fisica, chimica, geologia, paleontologia e mineralogia)

Fisica. — « *Impulse approximation* » *calculation of the polarization of the recoil proton in the reaction* $\gamma + n \rightarrow p + \pi^-$ *in deuterium.* Nota di MARCELLO BENEVENTANO, SILIO D'ANGELO, FRANCESCO DE NOTARISTEFANI, PIERO MONACELLI, LUCIANO PAOLUZI, FABIO SEBASTIANI e MARCO SEVERI, presentata (*) dal Corrisp. G. SALVINI.

RIASSUNTO. — Si esegue il calcolo in approssimazione impulsiva della polarizzazione del protone di rinculo nella fotoproduzione singola di mesoni π su nucleone in deuterio; il risultato cui si perviene mostra che tale polarizzazione, anche ad energie e momenti trasferiti sufficientemente alti, può essere diversa dalla polarizzazione del protone nell'analogo processo su nucleone libero. Questo risultato va tenuto presente nelle analisi fenomenologiche che utilizzano dati di polarizzazione ottenuti con bersaglio di deuterio.

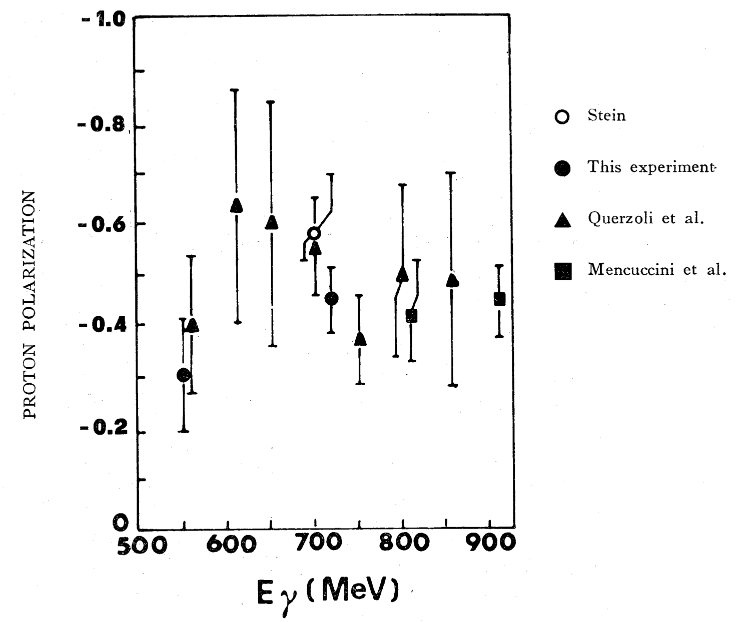
The experimental study of photoproduction on neutrons is made difficult by the lack of free neutron target. Since one can use only neutrons bound in nuclei, deuterium has been used for its simple structure and for its low binding energy. Therefore photoproduction of negative pions on neutrons is studied through the reaction

$$\gamma + D \rightarrow \pi^- + p + p.$$

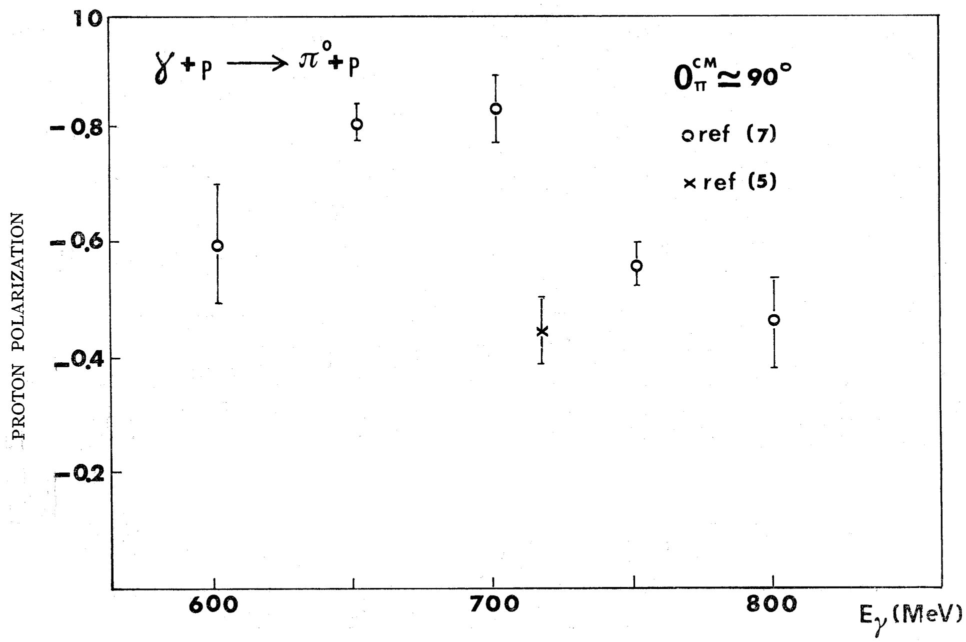
Lax and Feshbach [1] have calculated the cross section of this process using the « impulse-approximation » [2] and conclude that at sufficiently high energy ($E_\gamma > 2\, m_\pi c^2$) and at sufficiently high momentum transfer ($\theta_\pi^{C.M.} > 15°$) « impulse approximation » leads to results which are very similar to those obtained by the « spectator nucleon » model [3]. In this model one supposes that the photoproduction takes place on only one of the two nucleons in the deuterium, while the other (the spectator) maintains its initial momentum. The validity of this approximation has been confirmed, for what concerns pion-nucleon scattering, by the results of a π–D scattering experiment between 500 and 1000 MeV [4]; in this experiment the cross sections obtained on free protons are compared to those obtained on protons bound in deuterium.

Kenemuth and Stein [5] carried out a measurement of polarization of the recoil proton in the photoproduction of negative pions on neutrons in deuterium. These authors affirm that the weak binding energy of the nucleons

(*) Nella seduta del 15 novembre 1969.



a) Comparison of the experimentally measured polarization of the proton from $\gamma + p \rightarrow p + \pi^0$ reaction in deuterium with results obtained from the same process in hydrogen [5].



b) Comparison of the K. and S. results in deuterium with some recent data in hydrogen.

Fig. 1.

in deuterium permits to assume as a good approximation that photons with $E_\gamma \geq 200\,\mathrm{MeV}$ interact practically with free nucleons. To value the kinematical effects of the motion of the target proton, K. and S. measured the proton polarization in the reaction $\gamma + p \rightarrow p + \pi^0$ in deuterium and compared the results with those obtained for the same process in Hydrogen (fig. 1 *a*) and they concluded that the agreement is an indication that the momentum distribution of the nucleons does not affect their measurements of polarization.

However this agreement may be casual and, as we have recently carried out a set of measurements of the recoil proton polarization in the reaction $\gamma + n \rightarrow p + \pi^-$ in deuterium, we calculated this polarization in " impulse approximation " following the same phenomenological approach of Lax and Feshback [1].

The square modula of the amplitudes averaged over the initial states are, in the notations of L. and F.:

$$P_1^m = \frac{1}{3}\left[\sum_{m'} |\langle \chi_1^m | \tau_1 + \tau_2 | \chi_1^{m'} \rangle|^2\right] |O|^2$$

$$P_0^0 = \frac{1}{3}\left[\sum_{m'} |\langle \chi_0^0 | \tau_2 - \tau_1 | \chi_1^{m'} \rangle|^2\right] |E|^2$$

where

$$\tau_i = L + i\vec{\sigma}_i \cdot \vec{K}$$

is the photoproduction operator on free nucleon, with [6]

$$L = \mathcal{F}_2 \left[\frac{\vec{q} \cdot \vec{k} \times \vec{\varepsilon}}{kq}\right]$$

$$\vec{K} = \left[\mathcal{F}_1 - \mathcal{F}_2 \frac{\vec{q} \cdot \vec{k}}{kq}\right] \vec{\varepsilon} + \left[(\mathcal{F}_2 + \mathcal{F}_3) \frac{\vec{q} \cdot \vec{\varepsilon}}{qk}\right] \vec{k} + \left[\mathcal{F}_4 \frac{\vec{q} \cdot \vec{\varepsilon}}{q^2}\right] \vec{q} .$$

We therefore obtain

$$P_0^0 = \frac{2}{3} |\vec{K}|^2 E^2$$

$$P_1^1 = \frac{1}{3} (2 |L + iK_z|^2 + |K_y + iK_x|^2) O^2$$

$$P_1^0 = \frac{2}{3} (|L|^2 + |K_x|^2 + |K_y|^2) O^2$$

$$P_1^{-1} = \frac{1}{3} (2 |L - iK_z|^2 + |-K_y + Ki_x|^2) O^2$$

and the cross section is given by

$$\sigma_d = \Sigma P = \frac{2}{3} |K|^2 E^2 + \left[\frac{4}{3} |K|^2 + 2 |L|^2\right] O^2 .$$

At high energy of the incoming γ ($E_\gamma > 2\, m_\pi c^2$) and at high momentum transfer ($\theta_\pi^{C.M.} > 15°$) E^2 tends to O^2, therefore

$$\sigma_d \rightarrow 2\,(|K|^2 + |L|^2)\, O^2 \propto \sigma_n \quad \text{(cross section on the free nucleon).}$$

The polarization of the recoil proton, in the direction $\vec{k} \times \vec{q}$ coincident with the Z axis, is given in complete mixing hypothesis by

$$P_d = \frac{\frac{1}{2} Tr\,(\sigma_z^{(1)} \rho_{fin}) + \frac{1}{2} Tr\,(\sigma_z^{(2)} \rho_{fin})}{Tr\,(\rho_{fin})} = \frac{\frac{1}{2}(P_1^{+1} - P_1^{-1}) + \frac{1}{2}(P_1^{+1} - P_1^{-1})}{P_1^1 + P_1^0 + P_1^{-1} + P_0^0} =$$

$$= \frac{P_1^1 - P_1^{-1}}{\sigma_d} = \frac{\frac{2}{3}\,[4\, Im\,(LK_z^*) + 2\, Im\,(K_x^* K_y)]\, O^2}{\sigma_d}$$

where ρ_{fin} is the density matrix of the final states.

At high energy of the incident photon and high momentum transfer

$$P_d \rightarrow \frac{2}{3}\, \frac{2\, Im\,(LK_z^*) + Im\,(K_x^* K_y)}{|K|^2 + |L|^2} \neq$$

$$\neq P_n = \frac{2\, Im\,(LK_z^*) + 2\, Im\,(K_x^* K_y)}{|K|^2 + |L|^2} .$$

Therefore, although at high energy and high momentum transfer the cross section of the photoproduction on deuterium is proportional to that on free nucleons, the recoil proton polarization is different.

Similar results can be obtained for the photoproduction of π^0 on protons in deuterium.

Generally one arrives at similar results for the photoproduction of any meson on deuterium. Results are different in the case of the meson-nucleon scattering because in this process the spin flip part $\vec{K}$ is given merely by the product of a complex quantity multiplied by the unit vector normal to the reaction plane (in the photoproduction $\vec{K}$ is given by a linear combination, with complex coefficients, of the three unit vectors) and P_d and P_n differ only by a constant factor.

On the basis of the result obtained the polarization of the recoil proton in the process $\gamma + n \rightarrow \pi^- + p$ is not directly comparable with the polarization one should obtain on free neutron.

Moreover this result can be utilized in the photoproduction of π^0 on proton because it is possible to separate the contribution of $Im\,(LK_z^*)$ from that of $Im\,(K_x^* K_y)$ through the comparison of the result obtained from the measurement of the recoil proton polarization in hydrogen and in deuterium. We are working at an experiment to carry out measurements of this kind at different energies at the 1.1. GeV Frascati electrosynchrotron.

REFERENCES.

[1] M. LAX and G. FESHBACH, « Phys. Rev. », *88*, 509 (1952).
[2] G. CHEW and G. C. WICK, « Phys. Rev. », *85*, 636 (1951).
[3] D. WHITE, R. SCHELTMAN and B. CHASAN, « Phys. Rev. », *120*, 614 (1960).
[4] E. PAULI et ALTRI, « N. Cim. », *34*, 236 (1964).
[5] J. KENEMUTH and P. STEIN, « Phys. Rev. », *129*, 2259 (1962).
[6] C.G.L.N., « Phys. Rev. », *106*, 1345 (1957).
[7] J. BEALE, S. ECKLUND and R. WALKER, Report CTSL–42 (1968).